

TECHNICAL MEMORANDUM

EPA Region 5 Records Ctr.



313812

Date: May 29, 2007

To: Henry Nehls-Lowe
Bureau of Environmental and Occupational Health
Wisconsin Dept of Health & Family Services

From: Pei-Fung Hurst, URS Corporation

Subject: Comments on Human Health Risk Assessment
Ashland/Northern States Power Lakefront Superfund Site
Ashland, Wisconsin

This memorandum was prepared as a follow-up to the supplementary memorandum submitted on May 14, 2007 in response to review comments provided by the Wisconsin Department of Health & Family Services (WDHFS). These discussions addressed the revised draft human health risk assessment prepared as one of the Associated Documents with the revised draft Remedial Investigation (RI) Report for the subject site submitted to USEPA on January 25, 2007.

Potential risk to construction workers in utility trenches following dermal exposure to oily materials in groundwater water at Kreher Park was presented in the May 14, 2007 supplementary memorandum. This memorandum presents an evaluation, prepared as suggested by Mr. Henry Nehls-Lowe of WDHFS, of risks potentially associated with the construction worker exposure to volatile compounds in oily materials via inhalation.

Presented below is a brief description of the methodology used in this evaluation:

- ***Concentrations:***
Concentrations of volatile organic compounds (VOCs) reported in the groundwater sample collected from MW-7R on September 29, 2004 were used in this evaluation because these concentrations represent highest concentrations of VOCs detected in groundwater historically collected at Kreher Park.
- ***Fate and Transport Modeling:***
Concentrations of VOCs volatilizing from groundwater were estimated using a model provided by USEPA Region 8 (**Attachment A**). For the purpose of this evaluation, the default volatilization factor (VF) of 0.133 L/m³ (derived by Region 8 (based on the assumption of a trench that is 3 meter deep by 30 meter long and a wind speed of one mile per hour, and a mixing factor of 0.5) was used in the extrapolation of VOC concentrations in air inside the trenches from concentrations in groundwater using the following equation:

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Concentrations in air
= Concentration in water x VF

- **Exposure Parameters:**

Exposure parameters proposed for the construction workers as presented in the Work Plan for the subject Site were used in this evaluation. In addition, an exposure frequency (EF) of 1 day, as opposed to an EF of 250 days as presented in the Work Plan was also evaluated for informational purposes.

Presented below is a summary of potential risks estimated for construction worker exposure to VOCs in groundwater via inhalation while performing excavation or construction activities below the water table. Detailed calculations are presented in tables in **Attachment B**.

Chemicals	EF of 1 day		EF of 250 days	
	CR	HQ	CR	HQ
Benzene	8.77E-07	2.62E-01	2.19E-04	6.56E+01
Ethylbenzene	NA	8.40E-04	NA	2.10E-01
Styrene	NA	9.44E-05	NA	2.36E-02
Toluene	NA	3.84E-03	NA	9.61E-01
Trimethylbenzene 1,2,4-	NA	2.08E-02	NA	5.21E+00
Xylene, m- & Xylene, p-	NA	6.99E-03	NA	1.75E+00
Xylene, o-	NA	3.49E-03	NA	8.74E-01

CR: Cancer risk.

HQ: Hazard Quotient calculated for noncarcinogenic risk.

It should be noted that this evaluation was performed in response to comments provided by the WDHFS. This evaluation represents a conservative estimate of risks potentially posed by VOCs in groundwater without considering health and safety precautions that are typically implemented when workers are performing excavation activities below the water table.

ATTACHMENT A

REGION 8 VOLATILIZATION GUIDANCE



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
999
18th STREET - SUITE 500
DENVER, COLORADO 80202-2466

Ref: 8EPR-PS

To: Tracy Eagle, RPM Twins Inn
 From: Helen Dawson, Ph.D., Hydrogeologist, Superfund Program Support
 Date: July 29, 1999
 Subject: Derivation of a volatilization factor to estimate upper bound exposure point concentration for workers in trenches flooded with ground water off-gassing volatile organic chemicals.

This memo presents the derivation of a volatilization factor that can be used to estimate the upper bound exposure point concentration for workers in trenches flooded with ground water off-gassing volatile organic chemicals (VOCs). The derivation is based on a mass balance equation developed using a well-mixed, single-compartment model, also referred to as a box model. This approach is commonly used to estimate air concentrations in enclosed spaces (Andelman, 1985). In this approach, the chemical concentration everywhere in the "box" (e.g., the trench air compartment) is assumed to be the same. The VOC enters the box through emission from ground water at the base of the trench, as shown in Figure 1, and leaves the box by wind-induced convection. This scenario was chosen because it is the more conservative of the possible scenarios for workers in trenches. A volatilization factor developed for a trench that intersects moist contaminated soil, rather than ground water, would yield lower exposure point concentrations in trench air, provided the pore water concentrations were equivalent to ground water concentrations, because the chemical emission rate would be reduced by the required diffusion through soil.

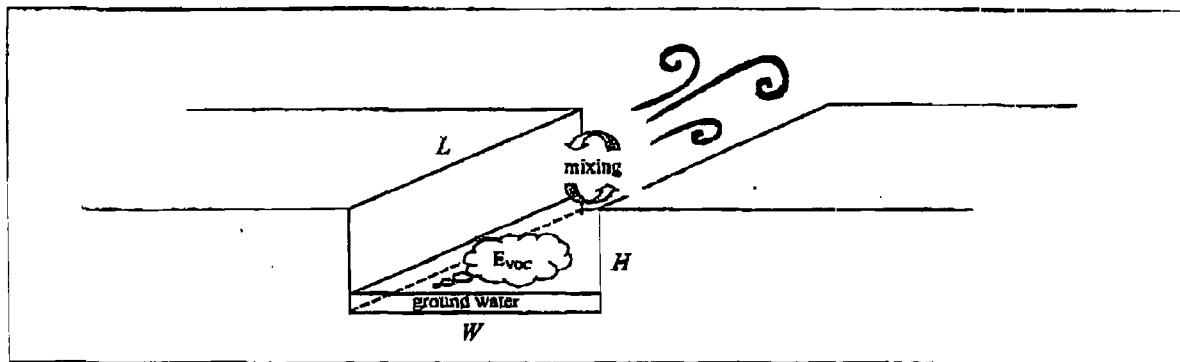


Figure 1. Scenario of exposure to workers in a trench flooded with VOC-contaminated ground water.

At steady state (a conservative assumption), the mass balance for the system depicted in Figure 1 is obtained by setting the emission rate (E) of chemical from water to air equal to the rate at which the chemical is carried away from the trench by exchange with the overlying air mass (after Schnoor, 1996, p.73; Andelman, 1985). Thus,

$$E_{VOC} = kNLWHC_a, \quad (1)$$



where E_{VOC} = emission rate of chemical from water to air [mg/sec],
 k = mixing factor (deviation from complete mixing in real conditions) [unitless],
 N = number of air exchanges per unit time in the trench [1/sec],
 H = height of the trench [m],
 L = length of the trench [m],
 W = width of the trench [m], and
 C_a = steady state, exposure point chemical concentration in trench air [mg/m^3].

Solving equation (1) can be for C_a yields

$$C_a = \frac{E_{VOC}}{kNLWH}. \quad (2)$$

In order to develop a volatilization factor for the scenario shown in Figure 1, an expression for E_{VOC} in terms of ground water concentration is needed. Guidance provided by the Superfund Exposure Assessment Manual (US EPA, 1988) recommends use of the following equation for volatilization from a surface water body to air:

$$E_{VOC} = k_{LG} A C_w, \quad (3)$$

where k_{LG} = overall mass transfer coefficient from the liquid phase to gas phase [m/sec],
 A = surface area of water body ($= LW$) [m^2], and
 C_w = chemical concentration in ground water ($\text{mg/l} \times 1000 \text{ l/m}^3$).

While ground water that has accumulated at the bottom of a trench is not strictly a surface water body, it can be considered a bulk liquid phase from which chemicals volatilize to air, which is the mechanism represented by equation (3). Thus, equation (3) is an appropriate model to apply in the scenario depicted in Figure 1. Substitution of equation (3) into equation (2) and canceling terms yields:

$$C_a = \left(\frac{k_{LG}}{kNH} \right) \left(\frac{1000 \text{ l}}{\text{m}^3} \right) C_w \quad (4)$$

Rearranging terms in equation (4) yields a volatilization factor (VF_{VOC}) for transfer of VOCs from ground water accumulations at the bottom of a trench to the air in the trench.

$$VF_{VOC} \left[\frac{1-\text{water}}{\text{m}^3-\text{air}} \right] = \frac{C_a [\text{mg}/\text{m}^3]}{C_w [\text{mg/l}]} = \frac{k_{LG}}{kNH} \left(\frac{1000 \text{ l}}{\text{m}^3} \right) \quad (5)$$

Equation (5) can be used to develop chemical specific volatilization factors for any volatile organic chemical. Alternately, a generic numeric VOC volatilization factor can be obtained by developing conservative estimates for k_{LG} , k , N and H , as described in the following paragraphs, that correspond to the scenario depicted in Figure 1.

The overall mass transfer coefficient k_{LG} is a function of the mass transfer coefficients for water and air on either side of the interface between the two phases, as shown in equation (6).

$$\frac{1}{k_{LG}} = \frac{1}{k_L} + \frac{RT}{H_c k_G}, \quad (6)$$



where k_L = liquid phase mass transfer coefficient [m/sec],
 k_G = gas phase mass transfer coefficient [m/sec],
 R = ideal gas law constant (8.2×10^{-5} atm·m³/mol·K),
 T = temperature (K),
 H_C = Henry's Law constant (atm·m³/mol).

For volatile chemicals (i.e., Henry's Constant greater than 1×10^4 atm·m³·mol⁻¹), the liquid mass transfer coefficient (k_L) is typically five or more orders of magnitude smaller than the gas phase mass transfer coefficient (k_G) and, consequently, mass transfer from water to air is limited by rate of mass transfer through the liquid. Thus, for a VOC, the overall mass transfer coefficient for water-to-air transfer is approximately equal to its liquid mass transfer coefficient.

$$k_{LG} \approx k_L \quad (7)$$

Liquid mass transfer coefficients (k_L) at 25°C can be estimated from the liquid mass transfer coefficient for dissolved oxygen and the aqueous diffusion coefficient of the chemical (Schwarzenbach et al, 1993), e.g.,

$$k_L = k_{L, \text{oxy}} \sqrt{\frac{D_{VOC}}{D_{\text{oxy}}}}, \quad (8)$$

where $k_{L, \text{oxy}}$ = liquid phase mass transfer coefficient for dissolved oxygen [m/sec],
 D_{VOC} = aqueous diffusion coefficient of the dissolved VOC [m²/sec], and
 D_{oxy} = aqueous diffusion coefficient of dissolved oxygen [m²/sec].

The liquid mass transfer coefficient for dissolved oxygen is a function of wind speed and is calculated as (Schwarzenbach et al, 1993):

$$k_{L, \text{oxy}} = 4.0 \times 10^{-6} + 4.0 \times 10^{-7} u \quad (9)$$

where u = wind speed 10 m above the water surface [m/sec].

The concentration of volatile organic chemicals in the trench will be highest on calm days, which corresponds to a wind speed of < 1 mph (Beaufort Wind Scale). Using this wind speed, the liquid mass transfer coefficient for dissolved oxygen is 4.2×10^{-6} m/sec.

For volatile organic chemicals, a conservative (large) estimate of D_{VOC} is 1.1×10^{-9} m²/sec. For oxygen, the diffusion coefficient at ambient temperature (25°C) is 2.1×10^{-9} m²/sec (Cussler, 1997). Applying these values to equations (7) and (8) yields a conservative (large) estimate for k_{LG} of 3.0×10^{-6} m/sec. This is equivalent to the conservative value obtained for volatile chemicals of concern at the Twins Inn site using the approach described in the US EPA Superfund Exposure Assessment Manual (1988), which is based on a ratio of molecular weights.

The number of air changes per day (N) in the trench can be estimated from the wind speed and the length of the trench, assuming (in the worst case) the long axis of the trench is parallel to the wind direction:

$$N = \frac{u}{L} \quad (10)$$

Assuming construction of a commercial building requires a trench length up to 30 m and using a cabin wind speed of 1 mph (0.45 m/sec), the number of air changes per day is conservatively estimated to be 0.015/sec. This value assumes uniform mixing in the trench. In homes, the proportion of the well-mixed volume to total volume ranges from 0.1 to 0.3 (i.e., the "dead" space not subject to complete mixing is approximately 70% to 90% of the total volume) (Andelman, 1985). Mixing is likely to be closer to complete mixing in an open trench, thus a value of 50% ($k = 0.5$) is assumed.

When applied to equation (5), the values calculated or assumed above for k_{LG} , k , N , and assuming the maximum trench depth (H) is 3 m, yield a conservative numeric VOC volatilization factor for the scenario shown in Figure 1.

$$VF_{VOC} \left[\frac{1 - \text{water}}{\text{m}^3 - \text{air}} \right] = \frac{(3 \times 10^{-6} \text{ m/sec})}{(0.5)(0.015/\text{sec})(3\text{m})} \left(\frac{1000 \text{ l}}{\text{m}^3} \right) = 0.133 \quad (11)$$

This calculated value is appropriate only for VOCs with Henry's Constants greater than $1 \times 10^4 \text{ atm} \cdot \text{m}^3 \cdot \text{mol}^{-1}$. Multiplying the volatilization factor by ground water concentration yields a conservative estimate of the air concentration to which workers in trenches with groundwater off-gassing VOCs could be exposed.

The generic VOC volatilization factor calculated in equation (11) is approximately 20% of the generic value calculated by Andelman (1985) for volatilization of VOCs in typical indoor water use for a family of four. This result is expected, as the mechanism for volatilization in a flooded outdoor trench is considerably less vigorous than that responsible for volatilization in typical indoor water use (e.g., showering), resulting in lower emission rates in the trench relative to an indoor scenario. However, the smaller volume of the trench, which has the effect of increasing concentration, counters the effect of the lower emission rate. Consequently, a five-fold difference between the two factors is reasonable and the value calculated in equation (11) is thus an acceptable, conservative ground water-to-trench air volatilization factor.

References:

- Andelman, J.B., Inhalation Exposure in the Home to Volatile Organic Contaminants of Drinking Water, EPA/600/J-85/342, 1985.
- Cussler, E.L., Diffusion, Cambridge University Press, 1997.
- Schoor, J.L., Environmental Modeling, John Wiley & Sons, New York, NY, 1996.
- Schwarzenbach, R.P., P.M. Gschwend, and D.M. Imboden, Environmental Organic Chemistry, John Wiley & Sons, New York, NY, 1993.
- US EPA, Superfund Exposure Assessment Manual, EPA/540/1-88/001, 1988.

EXAMPLE

Concentrations of VOCs in outdoor air (in trenches dug below the water table) were estimated using EPCs for groundwater and a volatilization factor provided by EPA Region VIII (Table 7-12). Appendix D explains development of the volatilization factor.

TABLE 5-21
Volatilization Factor for Water-to-Air
Transfer of VOCs in a Flooded Trench

$$VF_{VOC} = \frac{k_{LG} \times CF}{kNH}$$

Parameter		Value	Source
VF _{VOC}	Groundwater volatilization factor (L/m ³)	0.13	—
k _{LG}	Overall mass transfer coefficient (m/sec)	3.0x10 ⁻⁸	(1)
k	Mixing factor	0.5	(2)
H	Height of the trench in meters	3	(3)
N	Number of exchanges of air in trench (per second)	0.015	(4)
CF	Conversion factor (L air/m ³ air)	1000	—

(1) Derivation of water-side mass transfer coefficient is shown in Appendix D.

(2) Assumes uniform mixing in the trench.

(3) Site-specific estimate for maximum height of a trench dug to repair a utility line

(4) Assumes a trench length of 30 meters and a calm wind speed of 0.45 m/sec.

U.S. Environmental Protection Agency (EPA). 1997. Exposure Factors Handbook. U.S. EPA. Office of Research and Development. Washington, D.C. EPA/600/P-95/002Fa. August.

ATTACHMENT B

CALCULATIONS

Table 1
VOC Data for Monitoring Well NS-GWMW07R
NSP Lakefront, Ashland, Wisconsin

Well ID	Sampling Domain	Sample Identification	Chemical	Result (mg/L)	RDL (mg/L)
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	m & p-Xylenes	3.2	0.66
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	Ethylbenzene	3.9	0.35
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	Toluene	16	0.51
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	Styrene	1.3	0.35
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	sec-Butyl benzene	0.195 U	0.39
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	o-Xylene	1.6	0.33
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	1,2,4-Trimethylbenzene	0.57 J	0.36
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	Benzene	36	0.29
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	1,3,5-Trimethylbenzene	0.155 U	0.31
NS-GWMW07R	Kreher Park-Water Table	NS-GWMW07R-0904-092904	1,2,3-Trimethylbenzene	0.255 U	0.51

Values presented for nondetect or U-qualified results represent one half the RDL.
 ug/L - micrograms per liter
 RDL - detection limit

Table 2A
Exposure Parameters – Construction Worker

Exposure Pathway	Parameter	Description	Exposure Parameters			
			CTE	Source	RME	Source
Inhalation of Soil Derived Chemicals or Groundwater VOCs	IR	Inhalation Rate (m ³ /hour)	1.3	(n)	1.5	(o)
	ET	Exposure Time (hour/day)	8	(p)	8	(p)
	EF	Exposure Frequency (days/year)	219	(c)	250	(d)
	ED	Exposure Duration (years)	1	(e)	1	(e)
	BW	Body Weight (kg)	70	(g,h,i)	70	(g,h,i)
	VF	Volatilization Factor (m ³ /kg)	1.33E-01	(s)	1.33E-01	(s)
	ATrc	Averaging Time for Noncarcinogenic Effects (days)	365	(j)	365	(j)
	ATc	Averaging Time for Carcinogenic Effects (days)	25,550	(g,h,i)	25,550	(g,h,i)

Notes:

CTE - Central Tendency Evaluation

RME - Reasonable Maximum Exposure.

(c) In the absence of Site-specific information regarding future construction activities, the default industrial worker exposure frequency was used.

(d) In the absence of Site-specific information regarding future construction activities, the default industrial worker exposure frequency was used.

(e) Construction activities are assumed to occur over a 1 year period.

(g) US EPA, 1991. Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors.

(h) US EPA, 1989. RAGS, Volume I, Human Health Evaluation Manual (Part A).

(i) 70 kg body weight and 70 year lifetime are used to be consistent with the development of cancer slope factors.

(j) US EPA, 1989. RAGS, Part A. Averaging Time for noncarcinogens is equal to ED (year) × 365 days/year.

(s) Generic volatilization factor calculated for off-gassing VOCs in trench water.

Table 2B
Carcinogenic Toxicity Values

CAS Number	Chemical	SFI	SFI Source	Inhalation WOE
VOCs				
95636	1,2,4-Trimethylbenzene	NV	NCEA	c
71432	Benzene	2.73E-02	IRIS	A
100414	Ethylbenzene	NV	IRIS	D
NA	m & p-Xylenes	NV	IRIS	b
95476	o-Xylene	NV	IRIS	b
100425	Styrene	NV	IRIS	D
108883	Toluene	NV	-	C
1330207	Xylenes (total)	NV	IRIS	-

Table values are current for 02/06.

SFI – Inhalation Slope Factor

WOE – Weight of Evidence

NV – No Value

NCEA – National Center for Environmental Assessment

IRIS – Integrated Risk Information System

VOC – Volatile organic compound

WOE Classification System

Group Description

A Human Carcinogen

D Not classifiable as to human carcinogenicity

C Possible human carcinogen

USEPA's Carcinogen Assessment Group does not recommend a numerical estimate of toxicity.

b – This substance has not been assessed under the 1986 Cancer guidelines. Under the Draft Guidelines for Carcinogens Risk Assessment (USEPA, 1999), data are inadequate for an assessment of the carcinogenic potential of xylenes.

c – Under the Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005), there is inadequate information to assess the carcinogenic potential of toluene because studies of humans chronically exposed to toluene are inconclusive.

Table 2C
Noncarcinogenic Toxicity Values

CAS Number	Chemical	RfDi_C	Chronic Source	RfDi_S	Subchronic Source	Inhalation Target Organ
VOCs						
95636	1,2,4-Trimethylbenzene	1.71E-03	PPRTV	NV	-	CNS/blood/lung
71432	Benzene	8.57E-03	IRIS	NV	-	bone marrow
100414	Ethylbenzene	2.86E-01	PPRTV	2.90E-01	PPRTV	NA
NA	m & p-Xylenes	NV	-	NV	-	NA
95476	o-Xylene	NV	-	NV	-	NA
100425	Styrene	2.86E-01	IRIS	8.60E-01	HEAST	CNS
108883	Toluene	1.43E+00	IRIS	2.60E-01	PPRTV	lung/nervous system
1330207	Xylenes (total)	2.86E-02	IRIS	NV	-	nervous system
108-38-3	m-Xylene	NV	IRIS	NV	-	
106423	p-Xylene	NV	IRIS	NV	-	

Table values are current for 02/06.

RfDi_C – Inhalation Reference Dose (Chronic)

RfDi_S – Inhalation Reference Dose (Subchronic)

PPRTV – Provisional Peer Reviewed Toxicity Value

NV – No Value

IRIS – Integrated Risk Information System

NA – Not Applicable

HEAST – Health Effects Assessment Summary Table (HEAST), 1997

CNS – Central Nervous System

VOC – Volatile Organic Compound

Table 3A
Construction Worker: Inhalation of VOCs In Trench Air Volatilizing from Groundwater - Carcinogenic Effects

Carcinogenic Risk = $\frac{C_{\text{water}} \times SF_i \times IR \times EF \times ED \times ET \times VF_{\text{voc}}}{AT_c \times BW}$									
Equation Units	Risk	= (	C_{water}	x	SF_i	x	IR	x	EF
VOLATILES			mg/L	kg-day/mg		m ³ /hr	day/yr	hr/day	ET x ED x ATc / day
Benzene	2.19E-04	= (	3.60E+01	x	2.73E-02	x	1.5	x	250
Ethylbenzene	NA	= (	3.90E+00	x	NV	x	1.5	x	250
Styrene	NA	= (	1.30E+00	x	NV	x	1.5	x	250
Toluene	NA	= (	1.60E+01	x	NV	x	1.5	x	250
Trimethylbenzene 1,2,4-	NA	= (	5.70E-01	x	NV	x	1.5	x	250
Xylene, m- & Xylene, p-	NA	= (	3.20E+00	x	NV	x	1.5	x	250
Xylene, o-	NA	= (	1.60E+00	x	NV	x	1.5	x	250

Notes:

C_{water} – Concentration in Water

TR – Target Cancer Risk

BW – Body Weight, Adolescent (6 - 12 years)

ATc – Averaging Time, Carcinogens

SFO – Oral Slope Factor

IR – Water Ingestion Rate

EF – Exposure Frequency

ED – Exposure Duration

ET – Exposure Time

VF_{voc} – VOC Volatilization Factor

Table 3B
Construction Worker: Inhalation of VOCs in Trench Air Volatilizing from Groundwater - Non-carcinogenic Effects

$$\text{Noncarcinogenic Risk} = \frac{C_{\text{water}} \times IR \times EF \times ED \times ET \times VF_{\text{voc}}}{AT_n \times BW \times RfDi}$$

Equation Units	NC Risk	(C _{water}	×	IR	×	EF	×	ED	×	ET	×	VF _{voc}) + (BW	×	AT _n	×	RfDi)	
		(	mg/L	m ³ /hr	day/yr	yr	hr/day	yr	hr/yr	yr	hr/day	L/m ³	kg	day						
VOLATILES																					
Benzene	= (6.56E+01	3.60E+01	x	1.5	x	250	x	1	x	8	x	1.33E-01)	+	(70	x	365	x	8.57E-03
Ethylbenzene	= (	3.90E+00	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	2.90E-01
Styrene	= (	1.30E+00	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	8.60E-01
Toluene	= (	1.60E+01	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	2.60E-01
Trimethylbenzene 1,2,4-Xylene, m- & Xylene, p-	= (	5.70E-01	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	1.71E-03
Xylene, o- & Xylenes, Total	= (	3.20E+00	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	2.86E-02
	= (	1.60E+00	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	2.86E-02
	= (	1.60E+00	1.5	x	250	x	1	x	8	x	1.33E-01	)	+	(	70	x	365	x	2.86E-02

Notes:

C_{water} – Concentration in Water

TR – Target Cancer Risk

BW – Body Weight, Adolescent (6 - 12 years)

ATc – Averaging Time, Carcinogens

SFO – Oral Slope Factor

IR – Water Ingestion Rate

EF – Exposure Frequency

ED – Exposure Duration

ET – Exposure Time

VF_{voc} – VOC Volatilization Factor

Table 4A
Construction Worker: Inhalation of VOCs In Trench Air Volatilizing from Groundwater - Carcinogenic Effects

$$\text{Carcinogenic Risk} = \frac{C_{\text{water}} \times SFi \times IR \times EF \times ED \times ET \times VF_{\text{voc}}}{AT_c \times BW}$$

Equation Units	Risk	= (C_{water}	\times	SFi	\times	IR	\times	EF	\times	ED	\times	ET	\times	VF_{voc}	$+ ($	BW	\times	ATc)
			mg/L	kg-day/mg	m ³ /hr	m ³ /yr	day/yr	yr	hr/day	yr				L/m ³	kg	day				
VOLATILES																				
Benzene	$8.77E-07$	= (	$3.60E+01$	\times	$2.73E-02$	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550
Ethylbenzene	NA	= (	$3.90E+00$	\times	NV	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550
Styrene	NA	= (	$1.30E+00$	\times	NV	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550
Toluene	NA	= (	$1.60E+01$	\times	NV	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550
Trimethylbenzene 1,2,4-	NA	= (	$5.70E-01$	\times	NV	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550
Xylene, m- & Xylene, p-	NA	= (	$3.20E+00$	\times	NV	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550
Xylene, o-	NA	= (	$1.60E+00$	\times	NV	\times	1.5	\times	1	\times	1	\times	8	\times	$1.33E-01$	$+ ($	70	\times	25550

Notes:

C_{water} – Concentration in Water

TR – Target Cancer Risk

BW – Body Weight, Adolescent (6 - 12 years)

ATc – Averaging Time, Carcinogens

SFO – Oral Slope Factor

IR – Water Ingestion Rate

EF – Exposure Frequency

ED – Exposure Duration

ET – Exposure Time

VF_{voc} – VOC Volatilization Factor

Table 4B
Construction Worker: Inhalation of VOCs in Trench Air Volatilizing from Groundwater - Non-carcinogenic Effects

$$\text{Noncarcinogenic Risk} = \frac{C_{\text{water}} \times IR \times EF \times ED \times ET \times VF_{\text{voc}}}{AT_n \times BW \times RfDi}$$

Equation Units	NC Risk	(C_{water}	x	IR	x	EF	x	ED	x	ET	x	VF_{voc}) ÷ (BW	x	AT _n	x	RfDi)
			mg/l	m ³ /hr	day/yr	yr	hr/day	yr				L/m ³	kg	kg	day					
VOLATILES																				
Benzene	2.62E-01	=	(3.60E+01	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	8.57E-03)	
Ethylbenzene	8.40E-04	=	(3.90E+00	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	2.90E-01)	
Styrene	9.44E-05	=	(1.30E+00	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	8.60E-01)	
Toluene	3.84E-03	=	(1.60E+01	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	2.60E-01)	
Trimethylbenzene 1,2,4-	2.08E-02	=	(5.70E-01	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	1.71E-03)	
Xylene, m- & Xylene, p-	6.99E-03	=	(3.20E+00	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	2.86E-02)	
Xylene, o-	3.49E-03	=	(1.60E+00	x	1.5	x	1	x	1	x	8	x 1.33E-01	) ÷ (	70	x	365	x	2.86E-02)	

Notes:

C_{water} – Concentration in Water

TR – Target Cancer Risk

BW – Body Weight, Adolescent (6 - 12 years)

AT_c – Averaging Time, Carcinogens

SF_o – Oral Slope Factor

IR – Water Ingestion Rate

EF – Exposure Frequency

ED – Exposure Duration

ET – Exposure Time

VF_{voc} – VOC Volatilization Factor

Table 4A
Construction Worker: Inhalation of VOCs In Trench Air Volatilizing from Groundwater - Carcinogenic Effects

$$\text{Carcinogenic Risk} = \frac{C_{\text{water}} \times SF_i \times IR \times EF \times ED \times ET \times VF_{\text{Voc}}}{AT_c \times BW}$$

Equation Units	Risk	= (C_{water}	x	SF _i	x	IR	x	EF	x	ED	x	ET	x	VF _{Voc}) ÷ (BW	x	AT _c)
			mg/L		kg-day/mg		mi/hr		day/yr		yr		hr/day		L/m ³		kg	day		
VOLATILES																				
Benzene	8.77E-07	= (	3.60E+01	x	2.73E-02	x	1.5	x	1	x	1	x	8	x	1.33E-01	) + (	70	x	25550
Ethylbenzene	NA	= (	3.90E+00	x	NV	x	1.5	x	1	x	1	x	8	x	1.33E-01	) + (	70	x	25550
Styrene	NA	= (	1.30E+00	x	NV	x	1.5	x	1	x	1	x	8	x	1.33E-01	) + (	70	x	25550
Toluene	NA	= (	1.60E+01	x	NV	x	1.5	x	1	x	1	x	8	x	1.33E-01	) + (	70	x	25550
Trimethylbenzene 1,2,4-	NA	= (	5.70E-01	x	NV	x	1.5	x	1	x	1	x	8	x	1.33E-01	) + (	70	x	25550
Xylene, m- & Xylene, p-	NA	= (3.20E+00	x	NV	x	1.5	x	1	x	1	x	8	x	1.33E-01) + (70	x	25550	
Xylene, o-	NA	= (1.60E+00	x	NV	x	1.5	x	1	x	1	x	8	x	1.33E-01) + (70	x	25550	

Notes:

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VF_{Voc} – VOC Volatilization Factor

Table 4B
Construction Worker: Inhalation of VOCs in Trench Air Volatilizing from Groundwater - Non-carcinogenic Effects

Noncarcinogenic Risk =		$\frac{C_{water} \times IR \times EF \times ED \times ET \times VF_{Voc}}{AT_n \times BW \times RfDi}$						
Equation Units	NC Risk	C_{water} mg/L	IR m ³ /hr	EF day/yr	ED hr/day	ET yr	VF_{vac} L/m ³	$BW \times AT_n \times RfDi$ kg day
VOLATILES								
Benzene	$2.62E-01$	x	1.5	x	1	x	8	x 1.33E-01) + (70 x 365 x 8.57E-03)
Ethylbenzene	$8.40E-04$	x	1.5	x	1	x	8	x 1.33E-01) + (70 x 365 x 2.90E-01)
Styrene	$9.44E-05$	x	1.30E+00	x	1	x	8	x 1.33E-01) + (70 x 365 x 8.60E-01)
Toluene	$3.84E-03$	x	1.60E+01	x	1	x	8	x 1.33E-01) + (70 x 365 x 2.60E-01)
Trimethylbenzene 1,2,4-	$2.08E-02$	x	5.70E-01	x	1	x	8	x 1.33E-01) + (70 x 365 x 1.71E-03)
Xylene, m- & Xylene, p-	$6.98E-03$	x	3.20E+00	x	1	x	8	x 1.33E-01) + (70 x 365 x 2.86E-02)
Xylene, o-	$3.48E-03$	x	1.60E+00	x	1	x	8	x 1.33E-01) + (70 x 365 x 2.86E-02)

Notes:

C_{water} – Concentration in Water

TR – Target Cancer Risk

BW – Body Weight, Adolescent (6 - 12 years)

ATc – Averaging Time, Carcinogens

SFO – Oral Slope Factor

IR – Water Ingestion Rate

EF – Exposure Frequency

ED – Exposure Duration

ET – Exposure Time

VF_{Voc} – VOC Volatilization Factor